Evaporation-α-spectrum Oscillations: Myth or Reality

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The study of particle evaporation from hot compound nuclei allows one to explore a variety of nuclear properties such as aggregation of nucleons into clusters, nuclear shape polarization, etc.

In this work we concerned ourselves with the quest of nucleon clusterization in the bulk of a compound nucleus. Assume that a complex particle pre-exists in a compound nucleus before it is emitted. As the particle segregates from the rest of the nucleus, it senses its field, which may be a mean Woods-Saxon-like potential, or a local polarization field. This should result in formation of particle states with a certain width characteristic of the life-time of the cluster. As a result a strength function should arise which modulates the spectrum of the emitted particles. These optical-like modulations should superimpose on the bulk of the evaporation spectrum and may become observable in data of very high statistics when fitting the spectrum with a smooth "background" [1].

In our investigation of the effect we focused our attention on the study of α-particle evaporation. This is a very tightly bound particle, and may readily pre-exist its emission. We analyzed the α-spectrum from the reaction of ^{3}He on silver at different energies and observed oscillatory behavior of the residuals above statistical significance. See Fig. 1. Unfortunately, the data presented us only with a couple of modulations which can be attributed to a variety of effects in addition to optical resonances. Also, there may be imperfections in the statistical model which may generate oscillations rooted solely in the rigidity of the fitting function.

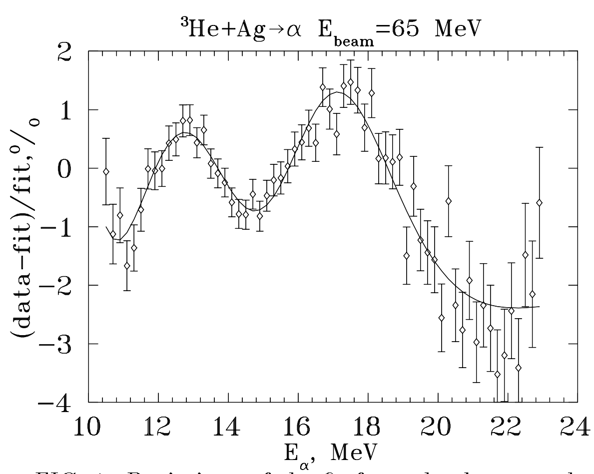

FIG. 1. Deviations of the fit from the data are shown for the spectrum of α-s emitted in the reaction ^{3}He+Ag $\rightarrow \alpha$, E_{beam} =65 MeV. The solid line on top of the data points is a modulation created using the modified model.

Such an impasse prompted us to consider alternative ways to the interpretation of the effect, one of which turned out to be quite successful. The modulations may be attributed to sequential emission of α-particles. At high excitation energies of the compound nucleus, the evaporation of α-particles becomes quite probable, and a competition with neutron emission is established. As a result of this competition, an α-particle may be emitted immediately after the formation of the compound nucleus, or after the first neutron is emitted, or after the second, and so on. This results in a distribution of emission barriers and temperatures for the emitting compound nuclei. When we experimentally observe the resulting singles spectrum in a Si-telescope, we see an integral of all possible modes of emission. If such an integral is fitted with a first-chance-emission model [1], deviations should arise. These deviations may carry important information on the widths of the distributions as well as the probability of each mode to occur.

Based on this assumption, an analytical procedure was developed that incorporates barrier and temperature distributions into the existing model. When compared to the first-chance-emission fits, oscillations were created identical to those from data. Fig. 1 shows an example of the oscillations deduced from the data and on top of them the oscillations produced with a modified model.

The fundamental idea behind the modifications can mathematically be presented in the following way:

$$\overline{S}\,(E_\alpha, B, T) = S(E_\alpha, \overline{B}, \overline{T}) + \frac{1}{2}\frac{\partial^2 S(E_\alpha, B, T)}{\partial B^2}\bigg|_{\overline{B}} \sigma_B^2 + \frac{1}{2}\frac{\partial^2 S(E_\alpha, B, T)}{\partial T^2}\bigg|_{\overline{T}} \sigma_T^2 + \frac{\partial^2 S(E_\alpha, B, T)}{\partial B \partial T}\bigg|_{\overline{B},\overline{T}} Cov(B,T) \quad (1)$$

where only quadratic terms of the Taylor expansion were retained. In this formula, S is the spectrum, B, T are emission barrier and temperature, E_α is the kinetic energy of α-particles, σ_B^2, σ_T^2 are the variances of the B and T distributions, and $Cov(B,T)$ is the covariance of B and T. The bar denotes average quantities. The formula shows that the average spectrum can be written as the spectrum of the average quantities (first chance) plus some higher order corrections accounting for the variances of the distributions and their covariance.

This method, in a simple way, allows one to experimentally obtain average values of the key quantities describing the α-evaporation process as well as their variances and a covariance. These later call for detailed modeling of the process to clearly understand the underlying phenomenon. The work is underway.

[1] L.G. Moretto, Nucl. Phys. **A247**, 211 (1975)